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Review Article

Polyvinyl Alcohol: A Comprehensive Study

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Abstract

Different polymers with versatile properties are attractive because of their introduction and potential uses in many fields. Synthetic polymers, such as PVA have prominent status as important and degradable materials with biocompatibility properties. This material has been developed in the 1920s and is remarkable because of their recyclability and consideration of the natural continuation of their physical and chemical properties. PVA is a colorless, water-soluble synthetic resin employed principally in the treating of textiles and paper. PVA is unique among polymers (chemical compounds made up of large, multiple-unit molecules) in that it is not built up in polymerization reactions from single-unit precursor molecules known as monomers. Instead, PVA is made by dissolving another polymer, polyvinyl acetate (PVAc), in an alcohol such as methanol and treating it with an alkaline catalyst such as sodium hydroxide. This review presents the structure, synthesis, properties, techniques used for characterization and applications of Polyvinyl alcohol (PVA). It digs deep in to the solid-state characteristics and solution properties of PVA. It digs deep in to the solid-state characteristics and solution properties of PVA. Over half a century, PVA is known as an auspicious material for diverse applications. It also focuses on different techniques used in the characterization of the polymer. The study also highlights recent biomaterial applications using PVA.

Keywords: Polyvinyl Alcohol (PVA); Solid State; Biocompatibility; Polymerization; Monomer

Abbreviations

PVA: Polyvinyl Alcohol; PVAc: Polyvinyl Acetate; SEM: Scanning Electron Microscope; DSC: Differential Scanning Colorimetry.

Introduction

Polyvinyl alcohol (PVA) was first prepared by hydrolyzing polyvinyl acetate in ethanol with potassium hydroxide by Hermann and Haehnel in 1924. It is produced commercially from polyvinyl acetate, usually by a continuous process. The acetate groups are hydrolyzed by ester interchange with methanol in the presence of anhydrous sodium methylate or aqueous sodium hydroxide. The physical characteristics and its specific functional uses depend on the degree of polymerization and the degree of hydrolysis. Polyvinyl alcohol is classified into two classes namely: partially hydrolyzed and fully hydrolyzed. Partially hydrolyzed PVA is used in the foods. Polyvinyl alcohol is an odorless and tasteless, translucent, white or cream-colored granular powder. It is soluble in water, slightly soluble in ethanol, but insoluble in other organic solvents. Typically, a 5% solution of polyvinyl alcohol exhibits a pH in the range of 5.0 to 6.5. The repeating unit for Polyvinyl Alcohol is shown in figure 1 below [1].

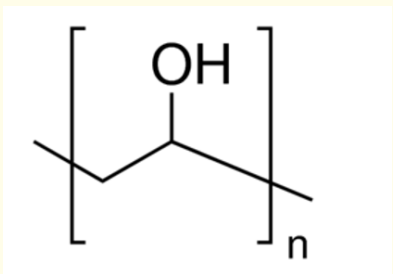

Figure 1: Repeating unit for Polyvinyl Alcohol.

Poly (vinyl alcohol) is the most commercially important water-soluble plastic in use. It is also be readily blended with a number of natural materials and can exhibit properties that are compatible

with a range of applications. The inclusion of natural fibers and fillers can give further improvements in mechanical properties without compromising overall degradability. Therefore, the potential benefits of this material given its water-soluble characteristics are huge, but this must be offset against practical considerations of its long-term life cycle in changeable environmental conditions [2].

PVA is an artificial polymer that has been used during the first half of the 20th century worldwide. It has been applied in the industrial, commercial, medical, and food sectors and has been used to produce many end products, such as lacquers, resins, surgical threads, and food packaging materials that are often in contact with food. PVA is a widely used thermoplastic polymer that is benign to living tissues, harmless, and nontoxic. This polymer is widely investigated because of its use in cross-linked products and nanofillers [3-5]. PVA is a biodegradable polymer, and its degradability is enhanced through hydrolysis because of the presence of hydroxyl groups on the carbon atoms. Moreover, it is water-soluble and has a hydrophilic nature [3,6-10]. Rates and environmental conditions for degradation may vary for many polymers, such as PVA [3,11-14]; these conditions include composting in the presence of oxygen, underneath soil layers, in aqueous media, and even in anaerobic circumstances [15]. For the structure of this paper, the review will be categorized into following points:

- Synthesis – Synthesis route I, II, III and IV.
- Solid State properties - Molecular weight, Tacticity, Crystallinity, Melting Point and Glass Transition
- Solution State Properties – Density, Surface tension, Rheology, Small angel X-Ray Spectroscopy
- Characterization – X-ray, FTIR, SEM, DSC
- Applications
- Conclusion

Synthesis

Polyvinyl Alcohol (PVA) is unique among polymers in a way that, it is not built up in polymerization reactions from single-unit precursor monomers. Instead, PVA is made by from another polymer [16]. There are 4 different ways of synthesis for PVA.

The method that is used is to hydrolyze polyvinyl acetate (PVAc) into PVA, which implies a chemical modification of the acetate 2 groups leading to alcohol groups. Since this chemical modification often is uncompleted the name PVA can also be the abbreviation for the copolymer of vinyl acetate and vinyl alcohol, P(VAc-co-VA), see figure 2.

An important aspect of PVA is that the degree of hydrolysis determines many of the mechanical properties that PVA possesses, for instance the tensile strength of 99% hydrolyzed PVA is 67-110 MPa and by only decreasing the hydrolysis degree with 10% the tensile strength is lowered to 24-79 MPa [17]. Also according to Shalaby., *et al*. (1991) the water solubility of PVA is strongly deteriorated as the hydrolysis degree is below 30 mol% [18]. Another important aspect that affects the mechanical properties is the molecular weight of the polymer. Commercially available PVA can be found in the molecular weight range of 30 000-200 000 g/mol, this is a low molecular weight for a radical polymer. It is explained by the fact that chain scission is very common due to the hydrolysis [19].

Figure 2: Polyvinyl alcohol-co-vinyl-acetate.

Synthesis route I

This is the route of synthesis for commercially available PVA. PVA is prepared by hydrolysis of radical polymerization of Polyvinyl Acetate (PVAc) in an alcohol such as methanol and treating it with an alkaline catalyst such as sodium hydroxide. The resulting hydrolysis, or "alcoholysis," reaction removes the acetate groups from the PVAc molecules without disrupting their long-chain structure. When the reaction is allowed to proceed to completion, the product is highly soluble in water and insoluble in practically all organic solvents. Incomplete removal of the acetate groups yields resins less soluble in water and more soluble in certain organic liquids.

Synthesis route II and III

Both routes of synthesis have been used only at lab scale. Polymerization of vinyl tert-butyl ether was carried out at -78oC with Boron trifluoride diethyl etherate in toluene and methylene chloride for synthesis route II and III respectively.

Synthesis route IV

This route has been used only in lab scale. PVA was derived from poly (vinyl trimethylsilyl ether), polymerized with ferric chloride in nitroethane at -78^{0}C [20].

Solid state properties

Solid state properties of a substance play an important role in selection of a substance and determine the formulation strategy. Different solidstate properties of PVA were investigated, which included molecular weight, tacticity, crystallinity, melting point and glass transition.

Molecular Weight [22]

PVA is represented by the formula $(C_2H_4O)_n$. The degree of polymerization n for commercially available materials lies between range of 500 and 5,000; equivalent to m. w. of 20,000 – 200,000.

Molecular Weight	Grade	Viscosity of 4% w/v aqueous solution at 20°C (mPas)
~200,000	High viscosity	40 – 65
~130,000	Medium viscosity	21 – 33
~20,000	Low viscosity	4 – 7

Table a

Tacticity [20]

The accurate determination of tacticity in PVA has been difficult and troublesome. Formerly, it was investigated by X-ray diffraction and infrared spectroscopy. Dyad and triad tacticities were studied by methylene and methine NMR spectra, respectively, but the overlapping of peaks is so severe, especially for the methane portion, that a quantitative determination has been difficult. On the other hand, it was disclosed that acetoxyl protons in PVAc derived from PVA are rather useful to the triad tacticity study although overlap still remains. Little attention has been paid to the NMR spectra of the hydroxyl protons in PVA. This neglect seems natural because heavy water was usually selected as the solvent and the hydroxyl protons and deuterons necessarily exchange between PVA hydroxyl groups and water so rapidly that hydroxyl protons under different environments cannot be discriminated by their NMR spectra. There is another good solvent for PVA, dimethyl sulfoxide (DMSO), which turned out to give the key to a useful investigation of the hydroxyl protons in this polymer. In DMSO solution, the hydroxyl proton resonance of PVA shows three well-resolved triad peaks with spin-spin splitting. The Tacticity of PVA depends on the method of synthesis. PVA is atactic in nature for commercially available grades.

Synthesis	Tacticity
Hydrolysis of Poly vinyl acetate	Atactic
Polymerization of vinyl *tert*-butyl ether in toluene	Isotactic
Polymerization of vinyl *tert*-butyl ether in methylene chloride	Slightly Syndiotactic
Polymerization of poly vinyl trimethylsilyl ether in nitroethane	Highly Syndiotactic

Table b

Crystallinity [22]

Semi-Crystalline nature of PVA arises from the well-known structure, shown in Figure 3. It has two polymer molecules running through each unit cell. Each repeating monomer contains two hydroxyl sites (an atactic structure). The polymer chains are described as lying along the b-axis of the unit cell. Bunn suggested two intermolecular hydrogen bonding directions, although recent molecular modelling results show that in addition to the intermolecular bonding, intramolecular hydrogen bonding is likely. The Bunn model for the crystal structure of PVA has been shown to fit better than the structure proposed by Sakurada., *et al*. 4 (which also contains atactic chains). The Bunn and the Sakurada structures are shown in Figure 3 for comparison.

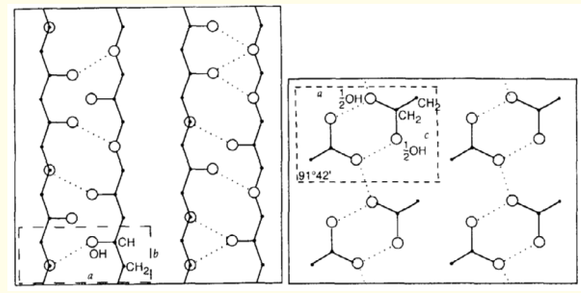

Figure 3: Bunn and Sakurada structure for PVA chains showing hydrogen bonding.

The difference between the two structures lies in the orientation of the molecules and the resulting intermolecular hydrogen-bonding directions within a very similar lattice. It is this hydrogen bonding which also controls the water solubility of the polymer, for although the amorphous regions of the polymer may be swollen by the ingress of water, the polymer will not dissolve until the crystal structure is broken down. Dissolution must involve the replacement of polymer-polymer bonds with polymer solvent bonds. PVA is dissolved in water at between 80 and 90°C with 30 min continuous stirring and cast onto glass, from which films 10-30 mm in thickness could be peeled. The water was removed from the solution, and the films completely dried by holding them at 50°C overnight. Once the films were cast, they were held in an atmosphere dried by silica gel. Films cast in this fashion were found to be around 30% crystalline, as measured by X-ray diffraction. A range of films prepared from aqueous solution and dried overnight at 50°C were annealed at different temperatures in the range 120-230°C in order to enhance the crystallinity, the samples being held between hot, thin PTFE sheets pressed onto a hot-plate. In each case the samples were annealed for periods which maximize the crystallinity at that temperature. For the lower temperatures this was about 1 h, and at the maximum temperature, 4 min. There was slight browning of those samples annealed at very high temperatures. After annealing, the samples were cooled rapidly on an aluminum block. The

samples were turned over halfway through the annealing time. The development of crystallinity as a function of annealing temperature was then followed by recording X-ray powder diffraction traces from each sample after the annealing treatment. The series of diffraction traces is given in figure 4, displaced from one another by an amount proportional to the difference in temperature.

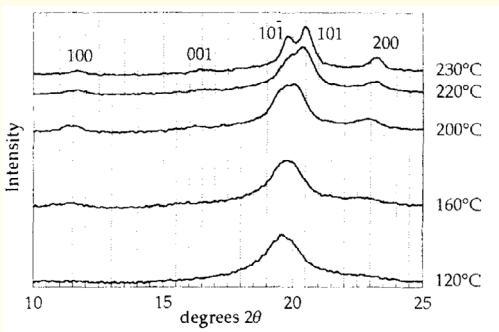

Figure 4: Effect of annealing temperature on crystallization.

Crystallinities were determined from the traces in Figure 4; the areas under the crystalline and amorphous components of each trace being measured after the application of a standard Gaussian curve-fitting routine to the peaks. The degree of crystallinity is found to increase in the range 38-50% with increasing anneal temperatures from 120 to 230°C.

PVAs with their crystalline structure consist of H-atoms interlinked between the hydroxyl group, and these hydrogen atoms could be interlinked. The crystallinity of PVA can be altered by addition of additives. A good example is shown by Kenawy et. Al. He showed that physically crosslinked PVA with hydroxyethyl starch (HES) can increase the crystallinity of PVA. It is related to hydrogen bonding between –OH groups of PVA and HES. Addition of HES in the physically crosslinked PVA network significantly influenced its molecular structure, thermal, mechanical, and morphological properties. PVA hydrogels were strongly dependent on HES contents. Physically crosslinked PVA–HES hydrogel gave more swellable, flexible, elastic, and higher protein adsorbent compared to that with only PVA. Additionally, HES incorporation to PVA hydrogel improved the thermal stability. The pure PVA xerogels exhibited lower T_g values in comparison to virgin PVA or blended PVA with HES up to certain content. Moreover, the overall thermal stability was notably improved by introduction of HES as blend materials. It was concluded the results that the physicochemical, morphological, mechanical, thermal and degradation properties showed that the addition of HES–PVA hydrogels is expected to improve utility as hydrogel membrane for biomedical applications, specifically for wound dressing application mildly [23].

Melting point and glass transition temperature

PVA shows a glass transition temperature at 85^0C and melting point is at 230^oC.

Solution properties

To determine the solution properties of PVA, PVA solutions in the concentration range from 2% to 14% (w/w) were prepared by dissolving the weighed amount of powder in distilled water at 90 C and gently stirring for 2h. Prepared solutions were tested for different solution properties like density, surface tension, rheology profile and SAX measurements.

Density

The measured densities of the PVA solutions for the entire investigated concentration range are presented in. figure 5 below.

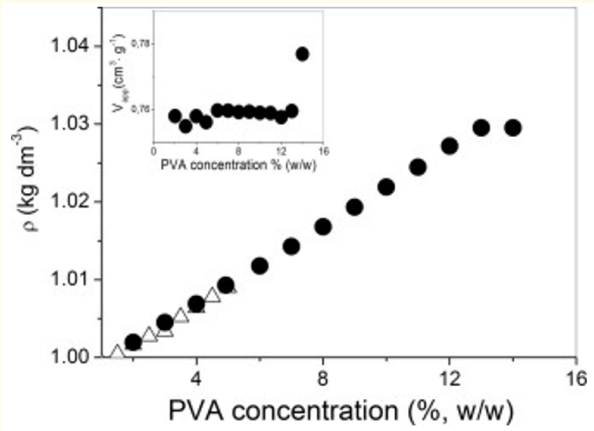

Figure 5: Densities of PVA solutions at different concentration.

Evidently, the density is increasing linearly with the increasing mass concentration of the polymer in the solution until the concentration of 13% (w/w) is reached. At concentrations higher than 13% (w/w) the measurements were not reliable due to the high viscosity of the system and the possible entrapment of air bubbles [24]. Comparing our results with the density measurements of PVA solutions performed by Salabat., *et al.* [25] it can be concluded that they observed the same trend even though their concentration range of PVA solutions was much lower, namely from 0.5% to 5% (w/w).

The apparent specific volume, V_{app}, is a parameter indicating a measure of the interaction between the segment of polymer and the solvent molecules [26]. It was calculated according to the following equation [27].

$$V_{app} = \frac{1}{d} \cdot \left[1 + \left(\frac{d_0 - d}{\omega \cdot d_0}\right)\right]$$

where d_0 and d are the densities of the solvent (water) and the solution, respectively, and ω is the mass ratio of solute to solvent (i.e., grams of solute per gram of solvent). The results are presented as an inset.

The values of V_{app} are very sensitive to the experimental uncertainties, which are larger in the case of more diluted systems; therefore, scattering for values in the low concentrations is expected. In the range between ~6% and ~11% (w/w) the value of V_{app} is nearly constant, i.e., ~0.76 $cm^3 g^{-1}$. At concentrations higher than ~13% (w/w) PVA V_{app} tends to increase. The V_{app} of a solution reflects the intrinsic volume of the solute molecules as well as the extent to which they interact with the solvent. Even more, when the solute is made up of flexible chain molecules, the V_{app} depends on the extent to which the molecules are extended or coiled in the solution and is thus an important parameter indicating structural changes within the solution with increased PVA concentration

Surface tension

At a lower concentration the PVA macromolecules are mainly present on the surface and acting as a surfactant, which reduces the surface tension. At a certain concentration, namely at 5% (w/w), the surface is completely occupied with the macromolecules and consecutively additional ones cannot be placed there anymore. This cause localization of additional molecules in bulk solution, which due to their intermolecular affinity start to rearrange and bond to form different structures. Formation of the latter causes also exclusion of the water and its position on the surface. Notably, the increasing amount of polymer in solution leads to increased number of possible internal structures and a larger amount of the squeezed water. The surface tension of the polymer solution is, therefore, approaching the value of the solvent's surface tension, which was measured to be 72 mN cm1 as shown in figure 6.

For concentrated PVA solutions there is no data available in the literature to be compared with the obtained results. On the other hand, our results for diluted PVA solutions are in good agreement with the published ones. Bhattacharya and Ray also reported a decrease in the surface tension with an increasing concentration of PVA from 0.001% to 3% (w/V), whereas the decrease is very sharp below 0.25% due to the greater attraction among the water molecules, leading to a water-pulling effect from the surface to the bulk. This means that the curve levels off and continues to fall slowly at higher concentrations [28]. They also showed that the surface tension decreases with a rise in the temperature as a result of the extended surface. Interestingly, Frisch and Al-Madfat proved that the surface tension of a 1% (w/V) PVA aqueous solution decreases with the aging, to such an extent that in 1 h the surface tension can drop by up to 10% [28]. To conclude, changing the polymer concentration in the solution causes motions and rearrangements of the molecules in the solution in such way that the higher is the concentration the less occupied is the solution's surface with dissolved molecules.

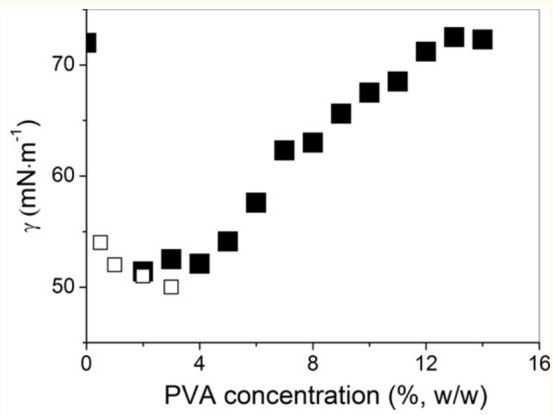

Figure 6: Surface Tension of PVA with concentration.

Rheology Profile [29]

The viscosity of the individual PVA solution is independent on the shear rate shown in figure 7; thus, the Newtonian behavior of these solutions can be assumed.

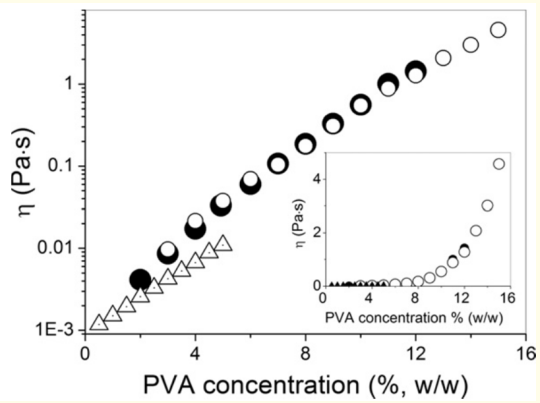

Figure 7: Rheology Profile of PVA.

It shows the obtained viscosity results as a function of the PVA concentration. The viscosities of the PVA solutions are increasing sharply with the increasing polymer concentration. Two completely different measuring techniques - rotational and capillary viscometer gave results that are in excellent agreement. These results completely confirm the Newtonian behavior of the PVA solutions.

Small Angel X-ray Spectroscopy (SAXS) measurements [30]

Figure 8 shows the experimental SAXS spectra of different PVA solutions, and the effect of the polymer concentration on the scattering intensity I in the investigated solutions can be clearly observed.

Figure 8: SAXS measurement of PVA solution.

In the inset a) of Figure 6, a Gunier plot of these data sets in a defined, small region of the scattering vector q is shown. Furthermore, the gyration radius, Rg, can be calculated from the linear part of the Gunier plot using the following equation

$$\text{Ln } I(q) = \ln I(0) - (Rg^2/3)q^q$$

where I(0) is the zero-angle intensity. The obtained values of R_g for all the investigated systems are gathered in the inset b) of Fig. 6. It is known, that R_g is the average distance from the center of mass of the polymer to the outside edge of the chain and thus it gives a sense of the size of the polymer coil. Evidently, R_g is only slightly dependent on the PVA concentration up to a concentration of _12% (w/w) PVA, however, two distinct regions can be observed in that lower concentration range anyway: the first up to _6% (w/w), where R_g = 2.5 ± 0.1 nm, and the second, the region between 7% and 11% (w/w) PVA, where R_g = 2.2 ± 0.1 nm. This finding is in agreement with the results of the surface tension measurements, c. To recall, the values of c lead to a conclusion that the macromolecules of PVA on the surface act as a surface-acting agent that reduces the surface tension of the solution indicating stronger interactions of the macromolecule's segments with water. Both findings correlated with the structure of macromolecules, which must allow molecules to be localized in the interface between the liquid and the gas. The latter is more likely to occur, when polymer chains are stretched. Finally, the stretched form of chains results also in the larger values of R_g, which were observed in the same concentration range 2–6% (w/w).

Characterization [30]

Different characterization techniques are used to characterize PVA. Some of these techniques are very well established. A review of these techniques was performed with help of some published literature work.

In one of the studies, Oxalic acid is blended to PVA and characterized. The polymer electrolytes of thickness (≈100 - 200 μm) were prepared in different weight percentage ratios [i.e. PVA: acid as 90:10, 80:20, 70:30 and 60:40] by solution cast method. These electrolytes are dried in vacuum at 10-3 Torr to eliminate the residual traces of water and stored in evacuated desiccators.

X-Ray Diffraction

X-ray diffraction studies of a) pure PVA, b) complexed PVA with Oxalic acid and c) pure Oxalic acid are performed using SEIFERT X-ray diffractometer (Cu Kα radiation) at room temperature with diffraction angle in the range 0-800. The X-ray diffraction spectra of pure PVA, complexed PVA with Oxalic acid and pure Oxalic acid are shown in figure 9.

Figure 9: X-ray diffraction of PVA with Oxalic Acid.

PVA has a characteristic peak at 20^0 indicating its semi crystalline nature. This peak of pure PVA becomes less prominent in complexed electrolytes indicating the decrease in intensity and gradual

broadening of the diffraction peak with the increasing oxalic acid concentration. This could be ascribed to the disruption of the PVA crystalline nature by Oxalic acid. Also, no sharp peaks corresponding to Oxalic acid are present in the complexed PVA electrolytes, suggesting the amorphous nature which clearly reflects a decrease in the degree of crystallinity in PVA.

FTIR Studies

The IR spectra of pure PVA, complexed PVA with Oxalic acid and pure Oxalic acid are shown in figure 10. The following changes in the spectral features have been observed after comparing the spectrum of complexed PVA with that of pure PVA and pure Oxalic acid.

Figure 10: FTIR spectra for PVA with Oxalic acid.

The absorption band in the region 3551-3114 cm^{-1} is due to inter molecular hydrogen bonded O-H stretching frequency of PVA which is shifted to 3603-3090, 3613-3101, 3623-2784, 3634-2824 cm^{-1} in the 10, 20, 30 and 40% acid complexed PVA electrolytes respectively. In addition to this, the C-H stretching of CH^2 showed an absorption band at 2947 cm^{-1} in pure PVA and is shifted to 2957 cm^{-1}, 2868cm^{-1}, 2743cm^{-1}, 2631 cm^{-1} respectively. The appearance of new peaks along with the changes in the existing peaks (and/or their disappearance) clearly indicates the complexation of PVA and Oxalic acid [30].

Scanning Electron Microscopy [30]

SEM micrographs are obtained for various samples of pure PVA, pure samples of Oxalic acid and PVA complexed with Oxalic acid in four different proportions by weight percentage (PVA: acid :90:10, 80:20, 70:30 and 60:40) are shown in figure 11.

Figure 11: Scanning Electron Microscope.

All the SEM micrographs shown in figures have been taken with comparable magnification around 10µm. It is seen from the micrograph of pure PVA in figure.9a. that pure PVA is semi-crystalline polymer with rough surface of several crystalline domains. The surface is rough and dispersed because of the presence of hydroxyl groups (OH) in PVA. On adding Oxalic acid, the PVA surface morphology changes from rough to smooth figure 9b. The incorporation of Oxalic acid into pure PVA seems to reduce the orientation of crystalline polymer and to convert the polymer morphology approaching to that of amorphous state. This result is consistent with the XRD pattern as discussed previously.

Differential Scanning Calorimetry (DSC) [31]

Typical plots of DSC curves of pure PVA and sodium montmorillonite complexed PVA polymer in different proportions are shown in figure 12.

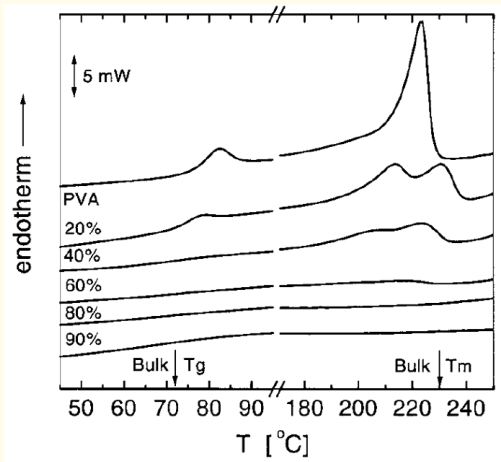

Figure 12: DSC for PVA.

It may be inferred that due to the addition of sodium montmorillonite to the PVA, there is a slight shift in the position of glass transition temperature (T_g) and/or melting temperature, Tm. In most of the cases the shift is towards lower temperature. This is followed by disappearance of melting transition. This is due to "neatly intercalated" nanocomposites, both the T_g and T_m are too weak and/or too broad to measure, or they are suppressed due to the polymer confinement. Although the physical origins of this behavior are still under debate, this absence of thermal events is in agreement with the general behavior of polymers intercalated in clays and synthetic silicates.

Applications

Bio-inertness and compatibility are other PVA properties that have implications in advanced medical fields, hemodialysis, drug delivery system, and implantable medical devices [32, 33]. PVA-based materials are used in pharmaceutical and in biomedical fields as drug carriers and are also applied in tissue engineering science [34-41].

It is used as a moisture barrier film for food supplement tablets and for foods that contain inclusions or dry food with inclusions that need to be protected from moisture uptake. Polyvinyl alcohol is not known to occur as a natural product [9].

Polyvinyl alcohol has various applications in the food industries as a binding and coating agent. It is a film coating agent specially in applications where moisture barrier/protection properties are required. As a component of tablet coating formulations intended for products including food supplement tablets, Polyvinyl alcohol protects the active ingredients from moisture, oxygen and other environmental components, while simultaneously masking their taste and odor. It allows for easy handling of finished product and facilitates ingestion and swallowing. The viscosity of Polyvinyl alcohol allows for the application of the Polyvinyl alcohol coating agents to tablets, capsules and other forms to which film coatings are typically applied at relatively high solids contents. 5.2 Food categories and use levels Polyvinyl alcohol may be used in high moisture foods in order to retain the overall satisfactory taste, texture and quality of the foods. Confectionery products may also contain Polyvinyl alcohol in order to preserve the integrity of the moisture sensitive constituents. Use levels for polyvinyl alcohol were developed by the sponsor assuming the application of 2.3 mg PVA/cm2 in aqueous film coatings. Maximum use levels of polyvinyl alcohol were derived for the final foods by selecting products within each food category with the greatest proportion of moisture sensitive components, estimating the surface area of those components, and assuming coating of the entire surface area with polyvinyl alcohol [10].

PVA hydrogels have been used for various biomedical. PVA hydrogels have certain advantages which make them ideal candidates for biomaterials. Advantages of PVA hydrogels are that they are non-toxic, non-carcinogenic, and bio adhesive in nature. PVA also shows a high degree of swelling in water (or biological fluids) and a rubbery and elastic nature and therefore closely simulates natural tissue and can be readily accepted into the body. PVA gels have been used for contact lenses, the lining for artificial hearts, and drug- delivery applications [9].

A great deal of work has been focused on development of articular cartilage using PVA. Oka., *et al*. inspected aspects such as lubrication, mechanical strength, load bearing capacity, attachment of material to the bone, etc. [13].

Noguchi., *et al*. found a new manufacturing process by which the tensile strength could be increased, which resembled human articular cartilage. It was found that upon implementation in rabbit knee joint, it was only slight inflammation, which disappeared after second week. This material had excellent bio adhesive properties.

PVA is mainly used in topical pharmaceutical and ophthalmic formulations. It is used as a stabilizer in emulsions. PVA is used as a viscosity increasing agent for viscous formulations such as ophthalmic products. It is also used in soft contact lenses. Peppas and Yang studied the transport of oxygen though pure PVA films. The

application of transdermal patches is being used as a component of the biomedical system because of the desirable PVA properties, such as water solubility and biodegradability. PVA cross-linked microspheres are used in oral precision relief systems [42].

It is used as a lubricant for contact lens solutions, in sustained release oral formulations and transdermal patches Ergotamine tartarate PVA buccal delivery for migraine headaches [20].

Hydrophilicity and processing characteristics allow this polymer to be mixed with other natural and artificial polymers [43]. PVA composites in hydrogel form have been used extensively in the medical field because of their biocompatibility, and are a well-known polymer gel with several applications, such as in organ replacement, drug delivery devices, and wound management [44-46]. From this point of view, encapsulating measurement nanoparticle (MNP) in PVA is a challenging and promising topic. PVA's good structure and biocompatibility with MNP, along with the cost of material, allow its biomedical and pharmaceutical applications [47,48]. PVA is a polymer that acts as a protective agent with formations in water solution and abundant OH groups; it also tends to absorb metal ions and form complex products [49-51]. Several research groups have investigated the application of nanotechnology in PVA, and they have reported their hydrogel preparation based on organically modified montmorillonite and studied their potential use as the main wound dressing devices *in vitro* [52] and *in vivo* [53] environments.

Conclusion

A comprehensive assessment was performed on the PVA which included in detailed study of its properties and applications. PVA can be synthesized in multiple ways, the most common being synthesis from Polyvinyl Acetate. The synthesis process can be manipulated to generate the biomechanical properties desired by changing molecular weight and tacticity. Crystallinity of PVA can also be modified using the advantage of it -OH groups. PVA shows typical solution properties of a polymer solution. PVA is an artificial polymer that has been used in the medical and other fields for the last 30 years. This polymer has been studied widely based on clinical and nonclinical research. As environmental concerns over the disposal of plastic wastes have grown and focus has switched towards product life cycle and disposal, poly (vinyl alcohol) has a readymade and viable disposal route. Though this has been extensively used, the literature shows that PVA still has plenty of potential applications in various fields of science and technology.

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Conflict of Interest

The author declares no conflict of interest.

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